CHAPTER 9
FISHWAYS

LIST OF FIGURES

9 FISHWAYS

9.1 Application

As identified in CDFG's Culvert Criteria for Fish Passage and NMFS' Guidelines for Salmonoid Passage at Stream Crossings, fishways are generally not recommended and should be used as a "last-resort" strategy where excessive drops and/or steep stream slopes occur. Fishways are an artificial means of correcting these types of situations. They are structurally intensive, site specific, and do not tend to mimic natural conditions. Detailed design of fishways requires significant expertise in hydraulic and structural analyses that go beyond the intended scope of this manual. Therefore, the information in this chapter provides an introduction to fishways for reference during the Planning Phase, and does not contain design direction.

All of the previously discussed design approaches for fish passage culverts are limited by a maximum slope that can be accommodated with the design. A common example is a culvert that was originally designed strictly for hydraulic performance that has developed a scour pool as a result of the high-energy discharge conditions. The drop at the scour pool combined with a degraded channel downstream may result in a change in elevation that cannot be corrected within the horizontal limits of the project using the maximum feasible slopes of the design approaches of the previous chapters. When the slope required exceeds the practical limits of other design approaches, a fishway may provide a solution when other strategy attempts have failed.

Some types of fishways, such as mechanical fish lifts, are appropriate only for large river systems or barriers where there is a large differential between the upstream and downstream water surfaces. The fishway classifications considered most appropriate for the range of stream sizes and hydraulic drops typical of a road crossing are:

- Step-pool ladders,
- Roughened channels, and
- Hybrid fishways.

These fishway classifications reflect basic differences in hydraulic design and the means used to dissipate excess energy. The first two classifications include more than one fishway type, providing design refinements to address various biological and physical parameters such as target species swimming characteristics, headwater variability, and debris and bedload movement. The following sections describe the basic design considerations and limitations.

9.2 Step-Pool Ladders

As the name implies, step-pool ladders create a series of pools with flow control devices between each adjacent pool that limit the difference in elevation so that fish are able to pass easily from pool to pool up the ladder. The pools are designed to dissipate the energy of flow entering from the pool above, creating an area where fish can rest before using burst speed or leaping ability to ascend to the next higher level.

Several basic designs for step-pool ladders have been developed in response to specific site and operating conditions that are typically encountered. Three types of step-pool ladders described further in this section are the pool and weir ladder, the Ice Harbor ladder, and the vertical slot ladder. Each has certain features that may be more or less suitable for a given site, depending on the hydrology and hydraulics of the site and the site topography. In addition, different species of fish move through fishways in different ways. Some species prefer to leap over each hydraulic drop while others tend to prefer submerged pathways. A fishway that forces fish to use a migration technique they are not suited to will often cause delayed passage.

9.2.1 Pool and Weir

Pool and weir ladders consist of a series of pools with the primary hydraulic control provided by sharp-crested overflow weirs between each pool. The weir frequently includes a notch to ensure minimum overflow depths under low flow conditions, and an orifice is often placed at the base of the weir to provide a passage route for non-leaping swimmers (Figure 9.1). A principal limitation of this design is the relatively narrow range of operating flow. The minimum recommended depth of flow over the weir is 3 inches, which can be especially difficult to maintain when the weir is also equipped with an orifice.

While both the effective volume and the kinetic energy of the entering flow typically increase along with increased flow rate, the kinetic energy increases more dramatically, reaching a point where the effective volume of the pool will no longer dissipate enough energy to provide effective fish passage conditions.

Figure 9.1. Pool and weir ladder.

The transition from plunging flow to streaming flow is determined primarily by the relationship of the weir crest to the water surface of the pool downstream of the weir. Plunging flow occurs when the downstream water surface is below the crest of the weir, which is also referred to as the "free-discharge" weir flow condition. Streaming flow occurs when the downstream water surface is higher than the weir crest, which is also referred to as the "submerged" weir flow condition. For fish passage, plunging flow is required for dissipation of kinetic energy. In the streaming flow condition the kinetic energy of the flow entering each pool tends to pass over the weir crests as a continuous surface jet, defeating the purpose of the pools as resting areas. Plunging flow will occur at lower flow rates, transitioning to streaming flow as flow rates increase, and the water surfaces of the pools begin to submerge the weirs.

9.2.2 Ice Harbor

The Ice Harbor ladder configuration (Figure 9.2) was developed specifically for the ladders at Ice Harbor Dam on the Snake River in Washington State. The design was developed in response to the need for a pool and weir type ladder that could operate effectively with a greater slope than is normally feasible.

Figure 9.2. Ice Harbor fishway (courtesy of U.S. Army Corps of Engineers).

The design is an adaptation of the pool and weir concept, where each weir has two overflow sections located adjacent to the walls and a baffle section in the center that does not overflow. The baffle section is constructed with flow stabilizers that extend in the upstream direction. Submerged orifices are provided directly below the overflow sections of the weir. Size of the ladder pools and geometry of the various weir elements was developed specifically by the US Army Corps of Engineers to maximize pool stability at a slope of 10 percent. The two ladders at Ice Harbor dam were designed to operate with a flow of about 70 cfs each. An adaptation of the design suited for smaller flows is the half Ice Harbor ladder, which is half of the full Ice Harbor ladder cut along the centerline. Although the design optimizes flow stability, the feasible range of operating flow is limited and a relatively constant forebay elevation must be maintained.

9.2.3 Vertical Slot

Instead of overflow weirs, flow in a vertical slot ladder is controlled by a narrow full depth opening between each pool (Figure 9.3). Width of the slot may vary, but is typically 1 to 1.25 feet. The advantage of vertical slots is that they can maintain favorable passage conditions over a much wider range of flow rates and tailwater or forebay water surface fluctuation. Energy is dissipated in each pool by the jet mixing with water in the pool. As the flow rate increases, the pool depths increase but the difference in elevation between the water surfaces in adjacent pools remains approximately constant. For this reason, this type of ladder is said to be self-regulating. Dimensions and configuration of the vertical slot and pool are critical to stability of the flow. Design of this type of ladder should conform to the dimensions of proven installations.

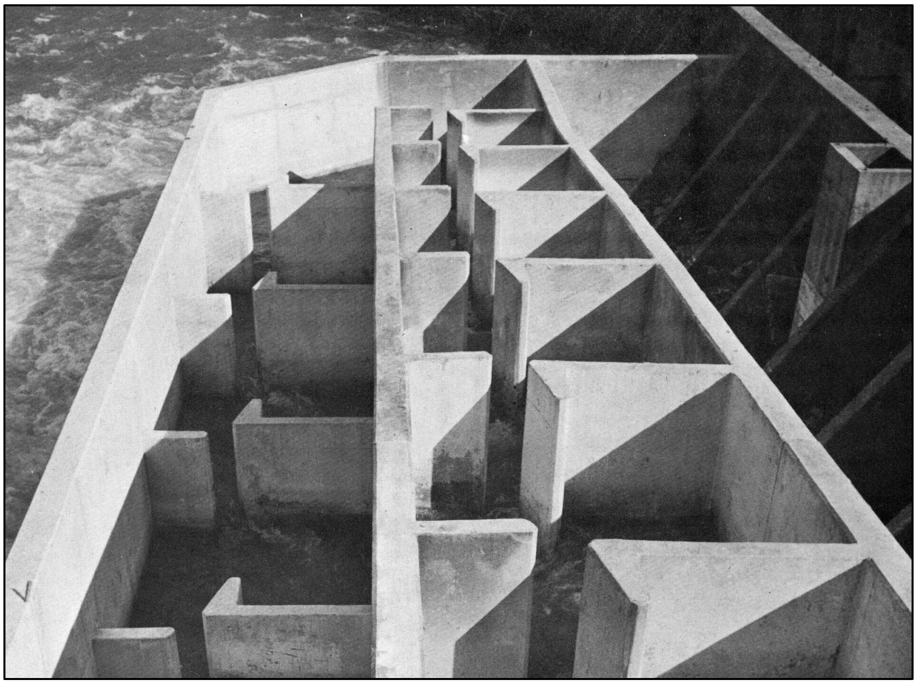

Figure 9.3. Vertical slot ladder (courtesy of U.S. Army Corps of Engineers).

The vertical slot concept is not suited to all species. Species that require overflow weirs to trigger a leaping response or that must orient to sidewalls may exhibit significantly delayed passage behavior in a vertical slot ladder. Another potential drawback of the design is a comparatively poor ability to pass debris due to the flow constriction presented by the slots.

9.3 Roughened Channels

In basic physical terms, the difficulty associated with steep slopes is an excess of energy. Due to the difference in elevation through the project area, water at the upstream end has potential energy. That potential energy is converted to kinetic energy as the water flows downhill to the lower elevation at the downstream end of the project. If the slope is steep, the potential energy represented by the overall elevation difference is converted to kinetic energy over a short distance, resulting in greater flow energy along the way compared to a shallower slope. Since the ability of fish to move upstream against the flow is limited, energy must be dissipated sufficiently to suit the swimming abilities of the fish that need to pass.

For the step-pool type ladders previously described, energy dissipation occurs at discrete locations along the way at the flow control structures that define each pool. An alternative concept is to increase the continuous dissipation of energy along the channel by increasing the roughness of the channel itself, thereby increasing the resistance to flow. A steep channel that is smooth will flow very rapidly, whereas flow in a rough channel with the same slope will be slowed down by the friction and turbulence induced by the roughness.

The concepts of roughened channels must be applied carefully in practice. Although turbulence effectively dissipates energy and thereby helps to decrease the average flow velocity, excessive turbulence itself can become a barrier to fish passage when the flow becomes so chaotic that fish can no longer orient to the required direction of travel.

9.3.1 Denil

The Denil fishway is an artificial roughened flume design that has been widely used throughout the world. Denil fishways are typically installed with a 17 to 20 percent slope and have been employed successfully at slopes up to 25 percent. The fishway itself consists of a relatively narrow flume with U-shaped baffles installed at short intervals (Figure 9.4). A wide range of flows are possible depending on fishway size, slope, and water depth requirements, but the fishway must be carefully engineered to provide the required passage conditions. Variation of the forebay water surface elevation must be limited to a range of approximately 1 m. The maximum feasible length of individual fishway segments is typically 9 m. Longer runs can be accommodated by installing individual segments of fishway with resting pools between segments where fish can recover before attempting the next climb. Denil fishways have been constructed using plywood, steel, aluminum, and concrete.

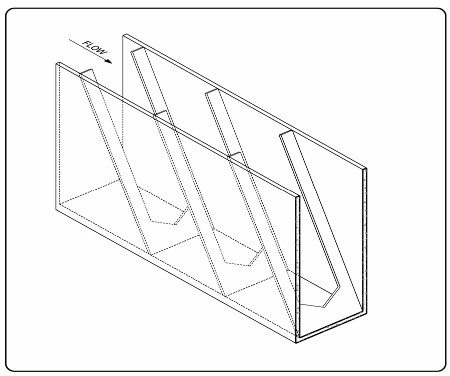

Figure 9.4. Denil fishway.

Denil fishways typically require a high degree of operational supervision and maintenance. The fishway must be kept completely free of debris to avoid altering the flow characteristics of the baffles, which would affect fish passage conditions.

9.3.2 Engineered Stream Channel

Constructed channel fishways are intended to replicate steep natural channels in much the same way as the Streambed Simulation design approach described in Chapter 5. Such channels have been constructed using either a series of control sills or rough rock linings. The use of control sills is a common method of revising a channel profile and is described in detail in Chapter 8.

For the rough rock lining approach, boulder-size roughness elements are placed in a pattern to optimize roughness as well as fish, flood flow, and debris passage. The boulders can be embedded into a cobble and gravel streambed for slopes up to about 5%, or anchored into a concrete channel subgrade for slopes up to about 8% (Bates 1992). There are no standard empirical methods for predicting fish passage through these fishways. Generally, they are designed to be stable for high structural design flows, and average velocities are used to predict fish passage conditions.

9.4 Hybrid Fishways

9.4.1 Pool and Chute

The pool and chute fishway was developed as an alternative to pool and weir ladders to permit operation over a wider range of stream flows. Instead of the simple horizontal crest of typical weirs, pool and chute weirs are vee-shaped overall with a low flow notch set into the apex of the vee. At low flow, the fishway performs as a pool and weir fishway with the flow plunging and dissipating in each pool. At high flow, a streaming flow condition exists down the center of the fishway where the bulk of the flow passes, but plunging flow and good fish passage conditions are be maintained at the edges of the pools.

Pool and chute fishways may be used where the total drop is less than about six feet. The recommended general configuration of the pool and chute fishway is based on observations of a number of pool and chute fishways (WDFW 2000). Recommended slope of the weir crest is 4H:1V. The high design flow for adult salmon should just fill the vee to the top of the sloped weir crest. At the design flow for juvenile salmon passage the water surface should be about three feet horizontally from the top of the sloped weir crest. The outer areas then remain as holding areas and passage corridors. The overall width of the fishway should be designed to provide these flow configurations relative to the design flows of the site. Recommended notch dimensions are width and depth equal to 15 and 8 percent of the fishway width respectively (Figure 9.8). It is suspected that the notch width could be as wide as necessary to provide additional flow capacity, but this has not been tested.

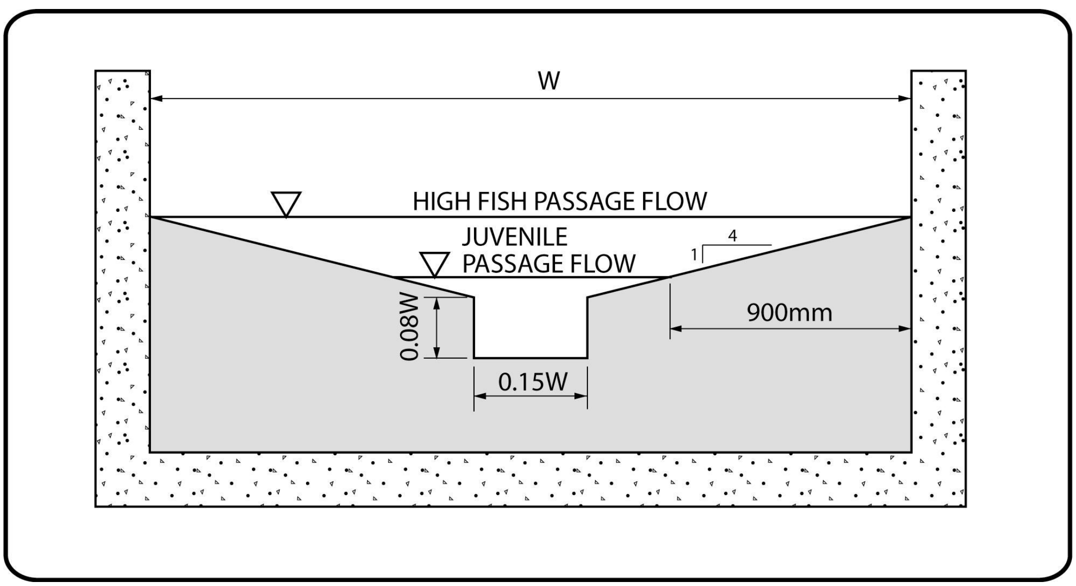

Figure 9.5. Pool and chute fishway section.

Model studies of pool and chute fishways have indicated that the streaming flow regime for the high fish passage design flow may not be achieved with fishway slopes greater than about 12 percent. Fishway slopes for high fish passage design flows greater than about 92 cfs may need to be even less. Specific design criteria for this type of fishway are still evolving as experience with them under various conditions is acquired.